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Brief Communication: A Study of the Predictive Accuracy of Mandibular Ramus Flexure as a Singular Morphologic Indicator of Sex in an Archaeological Sample

SUSAN JONES HAUN*
Department of Anthropology, University of Pennsylvania, Philadelphia, Pennsylvania 19104

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ABSTRACT Loth and Henneberg ([1996] Am J Phys Anthropol 99:473–485) assert that they have discovered a single morphologic indicator of sexual dimorphism in the human mandible that rivals the predictive accuracy of the complete pelvis at 94.2% for all samples (99% for healthy samples). To test the accuracy of their method, mandibles ($n = 150$) from the Tepe Hissar collection were assessed for the presence or absence of mandibular ramus flexure. These results were then compared to a separate sex assessment based on morphologic indicators from the corresponding skull and innominates (where possible) to yield an overall accuracy of only 78.2%. As a means of independent assessment, the mandibular results were also compared with Krogman's ([1940] Racial Types from Tepe Hessar, Iran, from late fifth to early second millennium, BC. Amsterdam: Koninkliijke Nederlandsche Akademie van Wetenschappen) assessment of sex based on craniofacial measurements and morphologic indicators from the skull. This comparison produced an even lower accuracy of 67.2%. Such results question the predictive potential of mandibular ramus flexure as a single indicator of sexual dimorphism and suggest caution when applying this method, especially in the case of fragmentary forensic and fossil remains. Am J Phys Anthropol 111:429–432, 2000.

Loth and Henneberg (1996) assert that the presence or absence of flexure on the posterior border of the mandible rivals the predictive accuracy of the complete pelvis at 94.2% for all samples (99% for healthy samples) as an indicator of human sexual dimorphism. Mature males exhibit flexure at the level of the molar occlusal plane on the posterior border of the ramus, while females of all ages and many subadult males display a straight border at that level. The presence of this flexure is hypothesized to result from "a change in the size, strength, or angulation of the muscles of mastication, especially the masseter and pterygoid" (Loth and Henneberg, 1996:481), which occurs during puberty as a response to hormonal changes. A study of subadult mandibles by Loth (1996) states that children of both sexes possess a straight ramus and that "flexure is not consistent in males until the end of adolescence" (Loth and Henneberg, 1996:482).

While Loth and Henneberg (1996:483) state that no one morphologic trait should be relied upon as an accurate assessment of sex, they nevertheless suggest that mandibular ramus flexure be applied to "fragmented mandibles from historic archaeological finds,

*Correspondence to: Susan Jones Haun, Dept. of Anthropology, University of Pennsylvania, 325 University Museum, Philadelphia, PA 19104. E-mail: shaun2@sas.upenn.edu

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rare fossil hominids, and modern forensic cases." Their preliminary studies indicating the presence of this trait in fossil hominids, lead them to predict that its use "will greatly enhance our ability to separate sexual dimorphism from evolutionary change" (Loth and Henneberg, 1996:483).

The ability of a researcher to properly identify and score a morphologic trait is crucial to any method's predictive potential. The purpose of this study is to test the predictive accuracy of Loth and Henneberg's method on a population that lacks an historic documentation of sex and age, a situation that will duplicate (at best) the conditions under which future assessment of archeological, fossil hominid, and forensic specimens will be conducted.

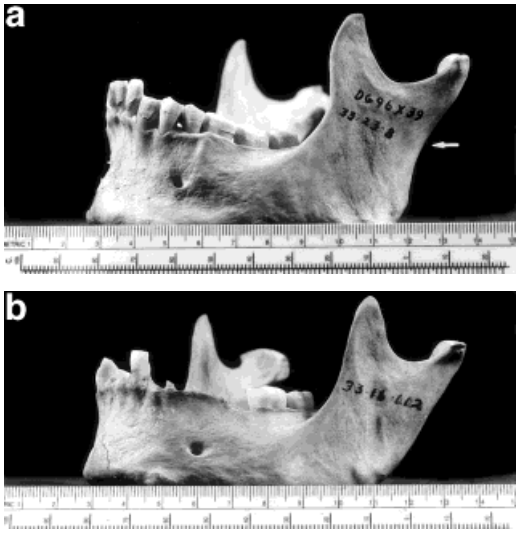

Fig. 1. (**a**) Flexure of the posterior border of the ramus at the molar occlusal plane is evident on this adult male mandible (arrow). (**b**) Adult female mandible. Note the straight border of the posterior ramus.

MATERIALS AND METHODS

The Tepe Hissar skeletal collection, a portion of which is presently curated in the University of Pennsylvania Museum of Anthropology and Archaeology, was excavated in 1931 under the direction of Dr. Erich F. Schmidt and analyzed by Dr. Wilton M. Krogman in 1935–1936. The site is located in a steppe region in northeastern Iran. Skeletal material assessed by Krogman are assigned to the following periods: Hissar I, before 4000 BC to ca 3500 BC; Hissar II, ca 3500 BC to ca 3000 BC; Hissar III, ca 3000 BC to ca 2000 BC; Sasanian Period, 350 AD; and Islamic Period, ca 800 AD (?) (Krogman, 1940). Currently only material from the Hissar III, Sasanian, and Islamic Periods is curated at the museum and available for this study.

Mandibles ($n = 150$) were visually assessed for the presence or absence of posterior mandibular ramus flexure following guidelines established by Loth and Henneberg (1996). These included a mix of healthy and pathological (as characterized by extensive tooth loss and/or bony pathologies) adult and older subadult individuals. Subadult age estimates were based on dental eruption patterns (Schour and Massler, 1944; Ubelaker, 1978) and evidence of occlusal attrition (Buikstra and Ubelaker, 1994). Individuals judged to be less than 16 years of age were excluded from the study. To eliminate preconceptions and scoring bias, the mandibles were separated from their respective crania and placed in another room for evaluation. The only identification present on each specimen was a museum catalogue number and/or a field number.

Initially, a random sample of 40 mandibles were examined to familiarize the investigator with the trait prior to scoring. It became quickly apparent that factors such as severe or differential occlusal attrition, and posterior angulation of the ramus made assessment more difficult. Following Loth and Henneberg, posterior mandibular ramus flexure noted at the level of the occlusal surface of the molars (Fig. 1a) was scored $+1$, a straight border (Fig. 1b) or flexure other than at the occlusal plane was scored -1, while ambiguous borders were scored 0. The scores of both right and left rami were then added to yield a score of $+2$, $+1$, 0, -1, or -2. Mandibles receiving scores of $+2$, $+1$, and 0 were designated males; scores of -1 and -2, females.

Crania ($n = 143$) and innominates ($n = 49$) were then evaluated separately for sex, and a general estimate of age using guidelines established by Buikstra and Ubelaker (1994). Subadult age for the skull was based on dental eruption patterns (Schour and

Massler, 1944; Ubelaker, 1978) and occlusal attrition (Buikstra and Ubelaker, 1994), while stages of union for the anterior iliac crest (Webb and Suchey, 1985) were used for the innominates. Individuals judged to be less than 16 years of age were eliminated from the study. These results where then compared with mandibular assessment of sex. Unfortunately, only 55 mandibles had corresponding cranial and/or postcranial elements present in the current collection (crania only: $n = 42$; innominates only: $n = 7$; both: $n = 6$).

To provide an independent assessment of accuracy, the mandibular scores were then compared to sex assessment determined by Krogman (1940) using crania only ($n = 61$). It should be noted here that of the identical crania ($n = 107$) assessed by this investigator and Krogman, 81.3% yielded the same results. Of those where disagreement occurred, there were more than twice the number of females (14 as compared to 6) identified as males by Krogman, than males identified as females. In addition, where both crania and innominates where available to this investigator for study ($n = 11$), there were no discrepancies in sex assessment between the two elements.

TABLE 1. Overall accuracy of ramus shape as an indicator of sex in the total number of Tepe Hissar individuals tested, and in adults only

Ramus shape scores[1]:	N	−1 and −2 N	−1 and −2 %	0 +1 and +2 N	0 +1 and +2 %	Accuracy by sex (%)
Total Sample						
Haun[2]						
Males	28	2	10.5	26	72.2	92.9
Females	27	17	89.5	10	27.8	63.0
Total	55	19	100.0	36	100.0	78.2
Krogman[2]						
Males	38	9	42.9	29	72.5	76.3
Females	23	12	57.1	11	27.5	52.2
Total	61	21	100.0	40	100.0	67.2
Adults Only						
Haun[2]						
Males	27	1	6.2	26	74.3	96.3
Females	24	15	93.8	9	25.7	62.5
Total	51	16	100.0	35	100.0	80.4
Krogman[2]						
Males	34	6	35.3	28	75.7	82.4
Females	20	11	64.7	9	24.3	55.0
Total	54	17	100.0	37	100.0	72.2

[1] Ramus shape scores of 0, +1, and +2 were deemed male; −1 and −2, female. Assessments are by Haun.
[2] Cranial and/or postcranial sex assessment is by Haun; Krogman (1940).

RESULTS

Results presented in Table 1, indicate that ramus shape was diagnostic for 92.9% of the males, but for only 63.0% of the females, with an overall prediction accuracy of 78.2%. Using Krogman's data (Table 1), 76.3% of the males and 52.2% of the females were correctly predicted with an overall accuracy of 67.2%. As Ubelaker (1978) notes, subadult sex estimation is difficult to assess in archaeological specimens and should, therefore, be considered tenuous at best. Removing subadults from the study yielded slightly improved results (Table 1), yet failed to approach those reported by Loth and Henneberg. Because a marked difference exists between prediction accuracies, misclassified mandibles and their corresponding cranial and postcranial elements were re-examined. Of the four females receiving a mandibular score of "0," two exhibited antemortem loss of all but one molar, and a third exhibited a very short mandibular ramus. Pronounced to excessive dental attrition was noted on two females receiving mandibular scores of +1 and +2, respectively. Pronounced posterior angulation of the ramus may have contributed to two other misdiagnosed individuals (one male scored a −1; one female scored a +1). Finally, a male receiving a mandibular score of −1 was judged to be in his late teens and may not have reached complete skeleto-musculature maturation, a condition which Loth and Henneberg state is often necessary for accurate assessment. Interestingly, completely edentulous specimens were correctly identified, even though excessive tooth loss places abnormal functional demands upon mandibular components.

DISCUSSION AND CONCLUSIONS

These results suggest that presence or absence of posterior mandibular ramus flexure may lack the degree of accuracy predicted by Loth and Henneberg and should be used with caution when the only available indicator of sex. Further, the existence and/or degree of trait expression may be population specific with both genetic and functional components. Moderate to severe dental attrition was observed on almost all adult speci-

mens from Tepe Hissar. Attrition was often differentially patterned with incisors and molars exhibiting the greatest wear. Curiously, attrition was most pronounced on the mesiolingual cusp of both maxillary first molars, often almost completely eliminating the cusp along a steeply angled plane beginning at the occlusal surface and continuing superiorly and lingually to the cemento-enamel junction, producing dentinal and ultimately pulpal exposure. The majority of subadult dentition also expressed the initiation of this pattern of attrition. The source of such patterning is possibly culturally induced, although the specific mechanism has yet to be explored. Loth and Henneberg (1996) note that tooth loss, extreme tooth wear, and possibly some population specific genetic factors appear to influence trait expression, all of which can create interpopulational differences.

Application of this technique to modern forensic cases and rare fossil hominids brings into question an additional concern. Since full expression of flexure may not be present until musculo-skeletal maturation is attained in males, assessment of age at death is crucial to any estimation of sex. Forensic cases involving fragmentary remains present a problem if the body of the mandible and other age indicators are not recovered. As Loth and Henneberg point out, the nature of the fossil record is fragmentary, with the mandible (or portions thereof) often the only element preserved or recovered. Even when an intact fossil hominid mandible and complete dentition are available for study, age assessment remains controversial. Studies conducted by Mann (1975) suggest that the timing of dental development of *Australopithecus africanus* and *A. robustus* is very similar to that of living human populations (as cited in Bogin, 1988). Using somewhat different criteria, Smith (1986) and Bromage and Dean (1985), demonstrated that Australopithecines and early *Homo* grew at rates more similar to living apes than humans (as cited in Bogin, 1988). Depending upon which growth and maturation study is used, different investigators could arrive at conflicting estimates of sex for the same specimen.

In conclusion, this study questions the predictive accuracy of mandibular ramus flexure as a single indicator of sexual dimorphism and suggests caution be used when applying this technique in the absence of other morphological and osteometric indicators, especially in the case of fragmentary forensic or rare fossil remains. It should be noted that the results achieved in this study are based upon the skeletal remains of a single archaeological population. As such, these results do not negate the potential applicability of the Loth and Henneberg technique to other ancient and modern populations, particularly where additional indicators of sex and age are present. Trait expression appears to be population specific, with both genetic and functional components. Accuracy increases when the age, oral health, and completeness of dentition can be assured.

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